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A "Link Trainer" for the Coronary Care Unit*

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The rhythm disturbances a cardiac patient may undergo during his stay in a coronary care unit are simulated by a digital computer, which displays electrocardiograms and other information on an oscilloscope. In each case, a series of options allow a student to initiate treatment or take other action. Some features of the program such as the scoring mechanism, transition tables, etc., are discussed in this article.

In the past few years the number of facilities specifically built and equipped to treat the acute phase of ischemic heart disease has rapidly multiplied throughout the Nation. New and highly sophisticated monitoring and resuscitative equipment has been developed and can be seen concentrated in a comparatively small physical area of the hospital.[1] A whole array of new concepts, a new philosophy and a fresh understanding of the patterns of behavior of coronary artery disease and its complications are rapidly evolving, resulting in improved methods of diagnosis and treatment.[2] These units offer, by the very nature of their organization and function, an optimum set up for patient care, clinical research and bedside teaching. Physicians, nurses and other members of the health team have witnessed, in a very short period of time, radical changes in the nature of their responsibilities and in the way their services to the patient are rendered. Hospitals in general, especially those with intensive coronary care units, are now increasingly committed to effectively train their staffs in the field of electronic medicine as related to monitoring and cardiac resuscitation.[3]

The system described in this article is specifically concerned with the nurse, since her traditional role in patient care has undergone the most drastic changes. This is the result of one simple fact—emergencies are frequent in a coronary care area and more often than not she is the only one in attendance when such an event occurs.[4] The attending physician may not be in the hospital when his patient has an episode of ventricular fibrillation and the house staff may be busy

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in other areas of the hospital. In the case of many institutions having intensive care facilities, there is no house staff and yet immediate and effective action must be taken when such circumstances arise. If the physician is present, he will take charge and conduct the treatment; otherwise, it must be the duty of the nurse to see that appropriate therapy is promptly instituted. Experience has shown that, in the vast majority of the cases, the cause of an acute episode occurring in the coronary care area is a cardiac arrhythmia with significant slowing, stopping or sudden acceleration or irregularity of the heart action. The nurse must be able to recognize the presence of a life threatening abnormality and correctly diagnose it and should know what the appropriate treatment is in each case. It is not necessary for her to master a thorough understanding of the complex mechanisms of impulse formation or conduction or the mode and site of action of the drugs used in such a unit but a working knowledge of the problems she will likely encounter during the course of her daily duties is highly desirable. This must include some decisions regarding etiology (i.e., electrocardiographic manifestations of digitalis overdosage) or therapy (what constitutes an indication for cardoversion or in which situations should a stand-by artificial pacemaker be turned on).

A computer-based, teaching-testing program for coronary care nurses has been developed and is presently in operation at the Latter-day Saints Hospital in Salt Lake City, Utah. The instrumentation used consists of a medium-scale, general purpose electronic digital computer* operating in a time-sharing mode under control of the MEDLAB monitor.[5] A remote station,[6] which includes a memory oscilloscope for write-out and plotting, a numeric keyboard and a series of labeled switches,† allows the user of the program to communicate with the computer (Figure 1). The time-sharing mode allows the simultaneous use of the program by more than one user. The program can be run from any of 19 remote stations located in this and four other hospitals, including stations in the coronary care units themselves.

The program simulates the rhythm disturbances a patient with an acute episode of ischemic heart disease might develop during his stay in a coronary care unit. It displays an electrocardiogram across the face of the scope in the same way the nurse sees it on the oscilloscopes of the intensive care unit, with the cathode ray sweep inscribing the graph from left to right as the electrocardiogram is being generated by the computer. First, a normal sinus rhythm is displayed when the program is called from the remote station. On the second sweep, an abnormal tracing is presented to the user. This tracing is randomly selected by the computer from a transition matrix containing 15 arrhythmias. External noise can be simulated by the computer and may appear at random in the tracings as 60-cycle interference, muscle tremor or, in some cases, suggesting a loose elec-

* Control Data Corporation (3300), Minneapolis, Minnesota.

† Beehive Electrotech (601 Storage-Display Unit), Salt Lake City, Utah.

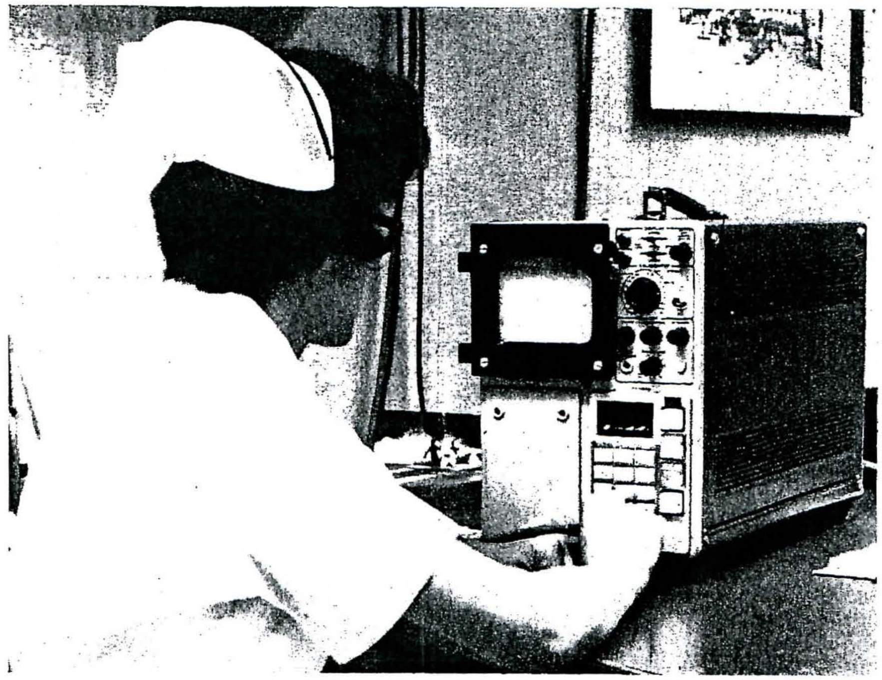

FIG. 1. Remote station.

trode. Below the tracing being displayed a message on the scope offers the information that three possible courses of action can be taken: (1) a medication can be given, (2) a procedure can be carried out, or (3) more information about the patient's condition can be obtained (Figure 2). The nurse faces a series of problems as the case is being presented to her—the first of these is to diagnose the condition of the patient. If she cannot diagnose the rhythm being displayed, one of the above options allows her to call for a consultation which causes the diagnosis to be displayed in the form of a message on the scope above the tracing. Still another option allows the student to ask for the optimal treatment and cause this to be displayed. She pays a price for this, however, since six points are subtracted from her score (see below) each time this option is used. In the same way, information regarding the patient's blood pressure can be obtained by selecting the proper option.

Once a diagnosis is established, which includes rhythm, blood pressure, technical quality of the tracing, etc., action can be taken by choosing the medication or procedure option. If medication is indicated, the nurse may select a drug from a list offered to her by the program, which includes digitalis, vasopressors, atropine, isoproterenol, lidocaine, procainamide and quinidine (Figure 3). If a

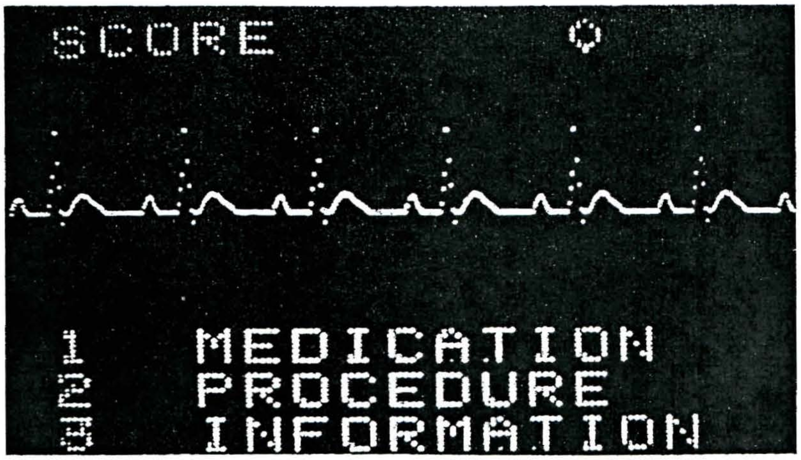

FIG. 2. Electrocardiogram and options for courses of action.

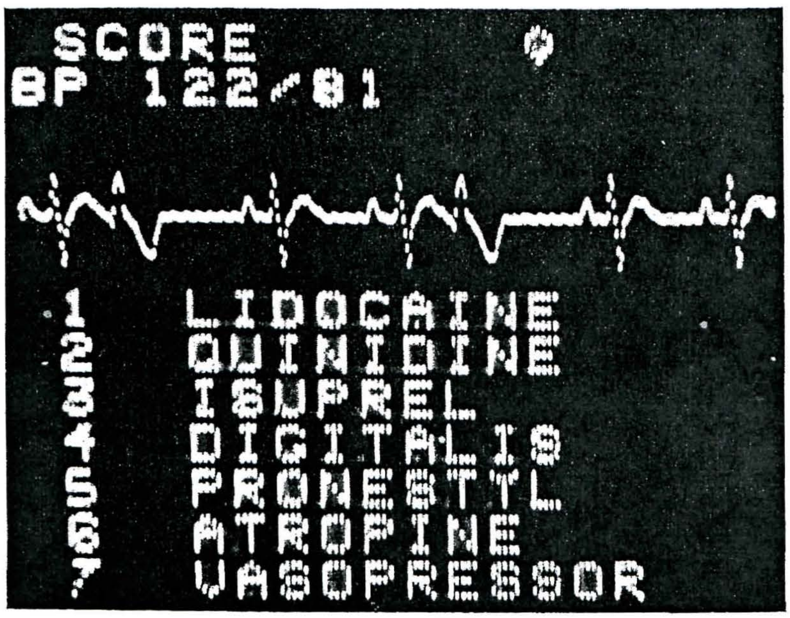

FIG. 3. Medication options. Score and blood pressure are also displayed.

specific procedure is in order, such as cardioversion, carotid sinus pressure or th use of a pacemaker, this can be entered through the numerical keyboard b pressing the numbered key corresponding to this option. If noise is present, i can be cleared by choosing the option labeled CHECK ELECTRODES. Whe a therapeutic decision is made and the corresponding action taken, a transition to a new condition will occur based on a random selection from the appropriate segment of the transition matrix (see below).

The program keeps a running score, based on the appropriateness of the decisions made, and continually displays this on the upper part of the scope (see below). If no decision regarding treatment is made by the nurse after two to four sweeps of the oscilloscope, the patient's condition will change again based on other elements in the transition matrix which reflect the expected natural course of the existing condition. If no treatment is instituted promptly in conditions such as ventricular fibrillation or hyperkalemia, a message on the scope will announce the patient's death after a short time. A new case can then be started or the session can be terminated.

At any point in the program the user can ask for a chart showing the course of events so far displayed, the blood pressure status at the time of each arrhythmia and whether the patient was taking digitalis (Figure 4). The chart will also indicate the treatment given by the user and the best therapeutic approach to have taken under these circumstances (optimum decision, see below). This information is automatically displayed by the program after ten consecutive changes in the patient's condition have taken place but can be requested by the student at any time. If, during the treatment, digitalis is given, the program must take this fact into account in subsequent therapeutic decisions since subsequent

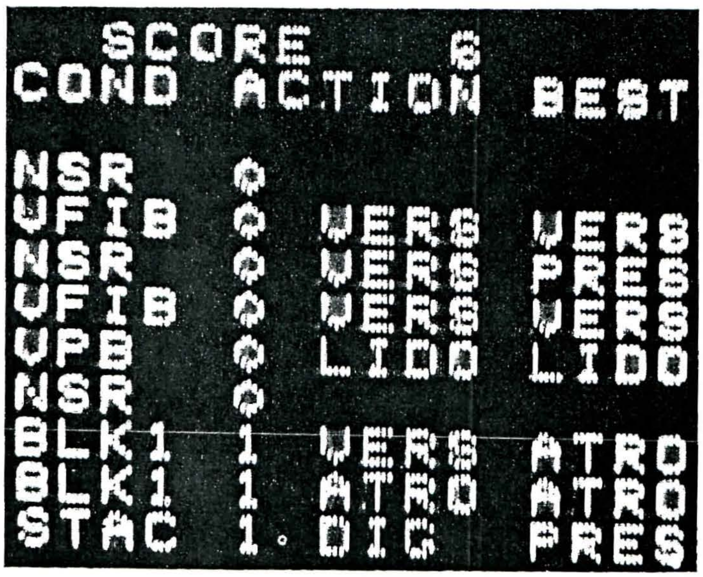

FIG. 4. Chart.

which condition according to these probabilities will be the new status of the patient.

To generate a random number, the computer samples the current reading of its internal 10KC clock and masks out everything but the last six bits (this will be a number between zero and 77 octal). This number will be random since the time between clock readings is variable due to the fact that it includes the time for the student to make his decision. The algorithm by which the computer selects the next state involves comparing this random number to the first probability in the appropriate segments of the table. If this probability is less than the random number, the second probability from the table is added to the first and another comparison made. If the sum is greater than the random number, the state corresponding to the second probability is chosen. To be more specific, if condition *A* were atrial fibrillation with rapid ventricular response (which diminishes ventricular filling and causes a fall in cardiac output and systemic hypotension [7]) the best action would be to use the DC cardioverter. This is not the only available effective treatment, however, but the one that has the highest probability of restoring normal sinus rhythm and normal blood pressure under these circumstances. However, in spite of this being the optimal choice in most cases with this set of circumstances, the procedure may induce ventricular fibrillation, because of a nonsynchronized discharge in the vulnerable phase,[8,9] or any other known or unknown factor.[10] Even if ventricular fibrillation does result, this treatment in general is the best choice and the student's score is increased accordingly. The same may apply to quinidine-induced ventricular fibrillation,[11] procainamide-induced hypotension [12] or a junctional tachycardia secondary to digitalis therapy.[13,14] In this teaching program all these factors are taken into consideration in the scoring mechanism and a positive number is added to the score when the decision made is a good one, regardless of what happens to the patient in the particular case. As another example to illustrate the point consider a hypotensive patient given isoproterenol when sinus bradycardia is present. In most cases the program will make him normotensive at the next transition. However, there is a real but small probability that ventricular tachycardia (or supraventricular with aberrant ventricular conduction) will result even though the score paradoxically increases. Simililarly, a negative number is added to the score when the action taken is not a good one.

With each decision a new score (NS) is calculated from the old score(OS) according to

$$\mathrm{NS} - \mathrm{OS} + 6(\mathrm{DX}/\mathrm{DXM} - 0.5) \tag{1}$$

where DX is a decision function defined by

$$\mathrm{DX} = \mathrm{PX} - \mathrm{PRX} \tag{2}$$

PX (benefit factor) is the probability that the chosen treatment will result in transition to normal sinus rhythm and normal blood pressure and PRX (risk factor) is the probability of the chosen treatment resulting in ventricular fibrillation or ventricular tachycardia (whichever is greater). DXM is the decision function for the optimal RX (the one having maximum DX).

In those cases in which no treatment is indicated, taking no action will increase the score. However, when an active decision is in order, it has to be made promptly since a delay in applying the appropriate measures may result in rapid deterioration of the patient's condition and finally his death (with an accompanying low score). This feature puts pressure on the student to make decisions quickly as he or she must do in the coronary care ward. Thus, the program becomes a realistic simulation of the situations commonly seen in a coronary care unit and allows the students to make decisions which affect the subsequent course of the simulation.

The probability tables currently used in this program are based on a review of the current literature on the subject and the authors' experience. These tables are only approximations to the actual probabilities but will be modified and improved as further pertinent data is collected from coronary care wards; the transition matrix provides an explicit format for this data collection. The program is flexible enough that new drugs or procedures can be added to the matrix, others can be deleted or changed and new tracings can be generated to represent additional arrhythmias.

Figure 6 shows a segment of a probability table corresponding to the specific situation of a patient with atrial flutter. In the first row, the symbol TAB12 references the computer to a location in magnetic core where this segment of the table is located, the 1 indicating that this table refers to a drug in the medication list and the 2 defining this drug as quinidine. If the student elects to administer quinidine to the patient, the program will reference one of the four cells in memory that form this segment of the table, according to the patient's condition at this time. The first and second and the fifth and sixth octal digits in each row indicate the probability that the administration of quinidine will cause the patient to go into the state indicated by digits three-four and seven-eight respec-

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PROBABILITY TABLE FOR QUINIDINE IN
ATRIAL FLUTTER

TAB12   OCT 40001013  NORMAL BP - NO DIGITALIS
        OCT 20004013  LOW BP    - NO DIGITALIS
        OCT 6000      NORMAL BP - DIGITALIS
        OCT 40001002  LOW BP    - DIGITALIS
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FIG. 6. Probability table.

tively. For instance, if this patient with atrial flutter receives quinidine when his blood pressure is normal and he has already been digitalized, the program will reference the third line of the table segment shown. The octal digits 6000 indicate that there is a 60/80 probability that he will go to condition 0 (normal sinus rhythm) at the next transition and an implied 40/80 probability that his condition will not change. If he has not been digitalized, the first line in this segment of the table will be referenced and there will be 40/80 probability of reverting to normal sinus rhythm (4000), a probability 10/80 of going to condition 13, which is atrial fibrillation with rapid ventricular response (1013) and an implied 30/80 probability that the rhythm will not be affected unless further action is taken. The second and fourth line in this segment illustrate the transitions that may take place when the patient is hypotensive (condition 02 being atrial fibrillation with slow ventricular response).

Certainly a limiting factor in the quality of patient care in a coronary care unit is the quality of the decisions made by the staff. This program is designed to give the nurse a concentrated experience in making these decisions based upon realistic data. A program is only as good as its ability to represent reality both in terms of the variety of the arrhythmias presented, the probabilistic nature of the transitions made and the fact that these transitions are based on real observations. In any given clinical situation the therapeutic decision is based on the assumption that this case will behave like the average case in the same situation. In the simulation program, however, the user is made aware that there are other possible responses, as is often the case in real life, and is allowed to gain experience in making these vital decisions without risking someone's life until he has optimized his decision-making capabilities.

The practical use of this program in the training of nurses already working or being trained to work in coronary care facilities during the past several months has been very satisfactory. More than 150 nurses trained and tested to date have shown definite improvement in their ability to make an adequate decision after properly evaluating the patient's situation in a short time, as evidenced by their ability to improve their scores on the "link trainer."

In conclusion, it should be mentioned that as the simulation of the coronary care unit becomes a more accurate reflection of reality it will also become a useful on-line tool for informing the nurse or the physician as to what action is the most adequate in a given situation. This will occur as machines become less expensive and the data base more adequate for performing this decision-making process.

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